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ON THE PERFORMANCE OF THE BENDIX LUMICON  
WITH ASTRONOMICAL OBJECTS

GERARD P. KUIPER

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RESEARCH AND DEVELOPMENT COMMAND  
UNITED STATES AIR FORCE

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ON THE PERFORMANCE OF THE BENDIX LUMICON  
WITH ASTRONOMICAL OBJECTS

FINAL REPORT

AF 19(604)-4540

Yerkes Observatory  
of the  
University of Chicago

Gerard P. Kuiper  
Principal Investigator

September 1959

Project 1773  
Task 17733

Space Flight Physics Laboratory  
GEOPHYSICS RESEARCH DIRECTORATE  
AIR FORCE CAMBRIDGE RESEARCH CENTER  
AIR RESEARCH AND DEVELOPMENT COMMAND  
UNITED STATES AIR FORCE  
Bedford, Mass.

## PREFACE

The photographic acquisition of fast moving artificial earth satellites is severely hampered by their faintness. It can be made more effective if provisions are made to use fully the integrating capability of the photographic emulsion by guiding the camera on the moving object with high accuracy and for the length of the exposure time. So far only the Baker-Nunn Satellite Tracking Cameras are capable of achieving this. Accurate guiding can be accomplished only if angular speed and direction of motion on the celestial sphere of the satellite are known with a correspondingly high accuracy. This is not always the case, particularly with new objects or objects which have been lost, and photographic techniques are almost useless for satellites whose orbital parameters are poorly known.

The study undertaken under Contract AF 19(604)-4540 with the Yerkes Observatory of the University of Chicago was to determine the suitability of a television technique for the discovery and observation of artificial satellites; in addition, tests were made to determine the performance of the apparatus in some astronomical problems. The results of the tests are very promising concerning satellite acquisition.

G. R. MICZAIKA

## INTRODUCTION

A series of astronomical and some laboratory tests were made with the Bendix-Friez Lumicon during the period December 1958 to July 1959 at the Yerkes and McDonald Observatories. The object of these tests was to assess the suitability of the Lumicon as a tool for astronomical research, including the discovery and observation of artificial satellites. The Lumicon was equipped with a General Electric No. Z-5294 Image Orthicon.

Relevant notes, comments, and recommendations are given which may assist in further tests or in future developments of the apparatus.

Three series of astronomical tests were run: (1) at Yerkes Observatory during December 1958 and January 1959; (2) at McDonald Observatory during March 1959; and (3) at Yerkes Observatory during July 1959.

The Yerkes tests included observations of the Moon, Venus, Mars, Jupiter, Saturn, star fields, and nebulae, with the 40-inch telescope. Further, tests with three short-focus, wide-angle lenses, for the recording of stars to the limiting magnitude, both for stationary star fields and fields moving at the rate of  $1^\circ$  per second (typical satellite velocity).

The McDonald tests included similar observations with the 82-inch reflector, placed at 6800 feet elevation, and with two of the three short-focus lenses.

The personnel was drawn from the Yerkes Observatory staff as needed, with Mr. Whitaker being the principal observer; and with Dr. Robert Hardie, of Vanderbilt University, Nashville, Tennessee, a specialist in electronics and television techniques, engaged as Consultant. Dr. Hardie made two extended trips to the Yerkes Observatory for the project. In the initial stages, Mr. E. M. Talbott, Sales Engineer of Bendix Aviation Corporation, Friez Instrument Division, 1400 Taylor Avenue, Towson, Baltimore 4, Maryland, was present at the Yerkes Observatory and instructed the several operators in the use of the equipment on the 40-inch telescope.

This report is subdivided as follows:

- A. Preliminary Adjustments
- B. Tests on Star Fields, Stationary and in Motion
- C. Tests on Nebulae (Unresolved Extragalactic, also Gaseous)
- D. Tests on Moon and Planets
- E. General Notes on Lunar and Planetary Photography
- F. Lumicon Performance

Sections A - D of this Report, based on tests made with the Lumicon, were prepared by Mr. E. A. Whitaker of the Yerkes Observatory and Sections E and F by Dr. Robert Hardie of Vanderbilt University.

The main conclusions are (1) the Lumicon is very fast in recording faint detail, provided this is stationary; (2) on moving objects and particularly on shifting planetary images its usefulness is limited and does not yet quite compete with photography. A tentative analysis of these findings is given in Section F.

#### A. PRELIMINARY ADJUSTMENTS

In the following test reports, the Lumicon was always electronically aligned and focused according to the instruction book before each test; further checks were occasionally made during tests to ensure that everything was functioning properly. Adjustments to the controls were also made in every case to give optimum results. Caution was always exercised when turning up the orthicon beam control to prevent damaging the target.

#### B. TESTS ON STAR FIELDS, STATIONARY AND IN MOTION

Preliminary tests were made at Yerkes in January at very low temperatures ( $-10^{\circ}\text{F}$ ). The camera unit was placed on a table outside the building, the monitor and pulse unit remaining just inside the door. A front-surface aluminized plane mirror was placed directly in front of the lens mount in order to reflect the zenith sky into the camera. Three commercial camera lenses were used for these tests: a) 150 mm focus,  $f/2.3$ ; b) 85 mm focus,  $f/2.0$ ; and c) 50 mm focus,  $f/2.0$ .

Optical focus was obtained by rotation of the focusing ring of the lens; the apparatus was then adjusted to give maximum visibility of faint stars i.e., aperture correction out, maximum gain). For each lens, a barely

visible star image was chosen and identified from the Bonner-Durchmusterung Charts; magnitudes were taken from the Bonner-Durchmusterung Catalogue, reduced to the Harvard (or General Catalogue) system.

Results (Yerkes Observatory, January 1959):

<u>Lens</u>	<u>Focal length</u>	<u>f. ratio</u>	<u>Aperture</u>	<u>Magnitude</u>
a	150 mm	f/2.3	65 mm	8.9
a	150 mm	f/16	9 mm	slightly fainter than 4.3
b	85 mm	f/2	43 mm	$9.2 + 9.6 = 8.7$
c	50 mm	f/2	25 mm	7.8

These results are shown in the accompanying graph (Figure 1). It is noted that the results for lenses b) and c) are not quite consistent with that for lens a) and those obtained later at McDonald; the cause for this is mentioned below.

No attempts were made at this time to determine the faintest magnitudes visible with various integration times.

Final tests on star fields were made at McDonald late March 1959 in more congenial temperatures. On this occasion, only lenses a) and c) were employed, but a special mounting for the plane mirror was constructed by Mr. Whitaker so that the portion of the sky viewed by the camera could be moved at a constant angular velocity. The mirror was driven by a specially made cam operated through an infinitely variable gear system driven by a small electric motor, the cam being of such dimensions and shape that the sky moved vertically on the kinescope screen at  $1^\circ/\text{second}$  for 15 seconds, paused for  $7\frac{1}{2}$  seconds, moved vertically in the opposite direction at the same speed for 15 seconds, and again paused for  $7\frac{1}{2}$  seconds.

First, static-field tests were conducted as before, with continuous scanning. Where possible, several faint star images were chosen and identified for each setting of the lens aperture. Care was taken now to ensure that the selected stars occupied sufficiently isolated positions so that neighboring stars did not contribute to the kinescope images.

After completion of the continuously scanned views, the unit was adjusted to an integration time of  $\frac{1}{3}$  second, i.e., three pulses per second, and limiting magnitudes were again determined. The instantaneous nature

of the pulse made discovery and identification of the faintest images a matter of some difficulty; for this reason, integration times greater than 2/3 second were not attempted.

Following the static star-field tests, the plane mirror was set in motion, and limiting magnitudes were again determined. No difficulties were encountered with continuous scanning, but the identification of star trails was very difficult when the unit was pulsing.

The results obtained are found in Table 1 and are given also in Figures 1 and 2. On this occasion, star magnitudes were obtained from the General Catalogue, except where stated.

Table 1

Lens	Focal Length	Focal Ratio	Aperture	Limiting Magnitudes for Integration Times of		
				1/30 sec.	1/3 sec.	2/3 sec.
a	150 mm	f/2.3	65 mm	8.8*, 8.6*	9.7*, 9.7*	fainter than 10.2*
c	50 mm	f/2.0	25 mm	6.1F5, 6.3M5 6.3KO, 6.6KO	7.8GO	8.6*
c	50 mm	f/2.8	17.9 mm	6.1F5	-	-
c	50 mm	f/4.0	12.5 mm	5.1A2, 5.6A2	-	-
c	50 mm	f/5.6	9.0 mm	4.3 Ao	-	-
c	50 mm	f/8	6.3 mm	3.5 Fo	-	-
c	50 mm	f/11	4.6 mm	fainter than 2.3KO, 2.6A3	-	-
c	50 mm	f/16	3.1 mm	2.3 Ko	3.5 Fo	4.4 Ao

\*Bonner-Durchmusterung magnitudes reduced to General Catalogue system  
STATIC FIELD, McDonald Observatory, 6800 ft.

Table 2

Lens	Focal Length	Focal Ratio	Aperture	Aperture <sup>2</sup> ÷ Focal Length	Limiting Magnitudes for Integration Times of	
					1/30 sec.	1/3 sec.
a	150 mm	f/2.3	65 mm	28.3	6.6KO, 6.3KO	6.6KO, 6.3KO
c	50 mm	f/2.0	25 mm	12.5	5.3B9, 4.8GO 5.2KO	5.7F5, 6.1F1 5.5G5, 4.9M2

MOVING FIELD (1° per second), McDonald Observatory



### Miscellaneous star tests

During the tests with the 40-inch telescope at Yerkes on the Orion nebula, the faintest stars visible on the kinescope were noted; these were of the 11th magnitude approximately. However, the test is not considered satisfactory since a K2 yellow filter was placed in the optical beam, the seeing was very poor, causing images to wander considerably and the Lumicon was adjusted for optimum visibility of the nebula.

During the McDonald tests, the unit was attached to the 82-inch reflector and set on NG4147, a sparsely populated globular cluster. Faintest stars visible with continuous scanning were of 15th magnitude; this agrees well with the theoretical result obtained by extrapolating the graph in Figure 1. With an integration time of three seconds the limiting magnitude was about 17.3, as shown in Figure 3.

### Discussion of results

From the graphs in Figure 1 it will be seen that with continuous scanning, the line lies exactly parallel to the theoretical line (for aperture increase by factor of 10, a gain of 5 magnitudes). The two results obtained in the Yerkes run which fall well above the line are explained by the fact that, with the small scale given by lenses b) and c), neighboring stars were contributing light to what, on the kinescope screen, was a single image.

Comparison of the graph lines in Figure 1 with those given in Figure 11 of the Proposal Booklet\* indicates that the Lumicon used is 0.9 magnitude less sensitive than expected. The orthicon apparently suffers from a kind of "reciprocity failure", as the line for an integration time of  $1/3$  second is 2.5 magnitudes below that indicated by the graph in Figure 11, op. cit. Curiously enough, however, the line for  $2/3$  second integration time is  $0^m.8$  fainter than that for  $1/3$  second, which appears to indicate no reciprocity failure between  $1/3$  and  $2/3$  second. Because of difficulties of choosing and identifying the faintest star images when pulsing, one may expect errors of a few tenths of a magnitude in these results.

\*Friez Instrument Division, Bendix Aviation Corp., Technical Proposal #1165



In the graph for a moving field, limiting magnitude is plotted against aperture<sup>2</sup>/focal length; this is done because the trail length produced in a given time is proportional to this ratio.

A peculiar phenomenon occurs when the mirror is moving; the trails produced on the kinescope by the moving star images are considerably wider than the stationary images, with the result that the surface brightness is appreciably lowered. Pulsing gives little gain in attempting to pick up moving stellar images, partly because of the difficulty of seeing a faint, blurred line in 1/3 second, and partly because pulses of more than a certain duration merely serve to lengthen the trail, not to brighten it.

### C. TESTS ON NEBULAE

While the preliminary star-field tests were being made at Yerkes, the Pleiades were centered on the kinescope. Using the 150 mm f/2.3 lens at full aperture, it was noted that the faint nebulosity surrounding this star cluster was clearly visible when using an integration time of 2 to 3 seconds.

The camera was later attached to the 40-inch refractor; a requisite yellow filter was placed in the optical beam in order to remove the out-of-focus blue light. The telescope was set on the Orion nebula. With continuous scanning the nebula was not visible on the kinescope, but pulsing rendered the brighter portions easily visible. The beam control could not be set in a position to give maximum visibility of the nebula and to discharge the brighter star images also. Attempts were made to photograph the kinescope image (Figures 4 and 5), but the extreme cold caused malfunctioning of the camera shutter; Figures 4 and 5 are therefore not of the best quality, though comparison with Figure 6 shows that the kinescope image is reasonably faithful and that the exposure time is enormously reduced. The 40-inch objective has a focal ratio of f/19.

Similar tests were made with the camera attached to the 82-inch McDonald reflector, the objects being the irregular extragalactic nebula M82 (Figures 7 and 8), and the nucleus of the elliptical extragalactic nebula M87 (NGC 4486), Figure 9. Excellent images of the former were obtained with integration times of approximately 2 seconds; unfortunately, the negative of Figure 8 was underdeveloped. With the latter nebula, the controls

were adjusted to give optimum views of the nucleus of the nebula, which is unusual in having an almost stellar nucleus and a bright, almost radial "jet." These features are shown in the photographs, and may be compared with a photograph taken with the 200-inch reflector in good seeing conditions, reproduced in *Ap. J.*, 123, 1956, p. 550.

#### D. TESTS ON MOON AND PLANETS

Preliminary tests were made at Yerkes in January with the camera attached to the 40-inch reflector. A K2 yellow filter was placed in the optical beam to remove the out-of-focus blue light, and provision was made for the interposition of a negative lens to give supplementary magnification. The telescope was first set on Mars, the only planet visible at that time, but little detail could be seen either visually through the 6-inch finder or on the kinescope.

With the instrument set on the Moon at full aperture it was found that the level of illumination was too high. Accordingly, the aperture was reduced until a reasonable light level was obtained. Under these conditions, it was noticed that in the kinescope image considerably less detail was visible than in the primary optical image (viewed before the camera was attached). Also, the severe restriction in the brightness range – already noted in the case of the Orion nebula and nearby stars – again became apparent, brightly illuminated portions of the lunar surface being undischageable without damage to the photocathode. Further reduction of aperture prevented this trouble, but the poorly illuminated portions of the lunar surface then became practically invisible.

A negative Barlow lens was next placed in position and the new optical focus found. The magnification being approximately four times the telescope could now be used at full aperture. Under these conditions, the amount of visible detail was increased, but the field of view was seriously decreased.

During the March run at McDonald, the camera was attached to the 82-inch reflector (focal ratio  $f/14$ ), with provision for the interposition of filters and a Barlow lens. With the telescope set on Venus and a supplementary magnification of 10 times, it was found that the intensity of illumination was still far too great. A neutral filter of density 2.0 was

interposed, with no improvement. Switching in "aperture correction" also failed to effect improvement. As a last resort, the mirror cover was closed until image intensity was correct. Under these conditions, an image of Venus was obtained on the kinescope, but it was too poor to be useful.

Subsequent tests on Jupiter were somewhat more successful; the supplementary magnification was reduced to approximately twice (equivalent focal length 200 feet) in order to accommodate the entire image of the planet on the kinescope, and the neutral filter (density 2.0) was left in position so that the correct intensity was obtained with the full 82-inch aperture. A photograph of the kinescope image was secured (Figure 10) and should be compared with one taken by direct enlargement onto photographic film shortly after the kinescope photo has been secured (Figure 11). It can be seen that there is a definite loss of detail in spite of the greatly reduced exposure time and that the areas of lowest brightness are almost absent from the kinescope image.

Attempts to obtain images of the Moon were unsuccessful for the same reason that the Venus tests failed, namely that the image brightness was too great. Trouble was also experienced from internal reflections in the Barlow-lens tube, notwithstanding the fact that the inside surface was matt black and a baffle was interposed. The lunar tests were repeated on two subsequent occasions, with similar results.

During the July run at Yerkes, tests were again made with the camera attached to the 40-inch refractor. The telescope was set on Jupiter, Saturn and the Moon, at a supplementary magnification of approximately 5 times (focal length 300 feet). Photographs of the kinescope were taken at moments of best seeing, and are included with this report. Shortly afterwards, direct photographs of the three objects were taken using Kodak Contrast Process Ortho plates without supplementary magnification. Jupiter is shown on Figures 12 and 13, Saturn on Figures 14 and 15, the Moon on Figures 16 - 19. Several more lunar comparisons were made but Figures 16 - 19 may be regarded typical. Enlargements made from these are included for purposes of comparison. It will be seen that the kinescope images are distinctly poorer in detail than the direct photographs, and that furthermore the field of view is greatly reduced.

With supplementary magnification of 5 times, the effective focal ratio of the 40-inch refractor is approximately  $f/100$ . At this value, the photocathode should be able to pick up all the detail present in the original optical image. That it does not do so and is, in fact, inferior to a photographic emulsion, is presumably due to two causes: (1) the phenomenon noted in the star-trail tests, namely, broadening of moving images; and (2) image persistence on the kinescope phosphor. In normal seeing conditions an element of the image moves over a limited area of the photocathode in a haphazard manner; the image on the kinescope of this moving element will be both broadened by the phenomenon referred to under (1) and lengthened by image persistence of the phosphor. The final lunar image on the kinescope will therefore be more blurred than the original optical image incident on the photocathode.

One may show that this explanation is correct by placing one of the short-focus lenses in the camera, and pointing the latter at a brick wall or other suitable object. When the camera is stationary, considerable detail is visible in the kinescope image, the limiting factor being the resolving power of the whole unit; on slowly rotating the camera, however, one finds that the smaller detail vanishes, and even coarse detail becomes indistinct. Possible schemes of circumventing this defect are considered in section F.

Difficulty was experienced at maximum gain settings by the appearance of rolling bars on the kinescope image. It was discovered later that the camera chassis was electrically live, and small sparks were emitted when the chassis was grounded. Whenever possible the camera was insulated, therefore, but this did not completely remove the trouble. The electrical equipment operating the telescopes and domes may have caused this interference.

The raster was frequently imperfect when the unit was first switched on, having several positions of start and finish of the sweep lines. Adjustment of "R80" usually cured the trouble, but this adjustment was very critical, and frequently had to be slightly altered during the night's run. Trouble was also found in the brightness control, with sudden jumps in brightness of the kinescope image occasionally occurring.

## **E. GENERAL NOTES ON LUNAR AND PLANETARY PHOTOGRAPHY**

**GOAL:** to achieve higher-resolution photographs.

### **LIMITATIONS IN CONVENTIONAL PHOTOGRAPHY:**

Even the best existing photographs taken with large telescopes do not exploit the full resolving power of the instrument.

The resolution has always been limited by the atmospheric seeing. Since this is characterized by two kinds of effects, viz. (1) translation of the image, and (2) dilation of the image, we must examine how best to minimize each.

#### **I. TRANSLATIONAL MOTION**

Here we must either (a) stabilize the image or (b) use sufficiently short exposures to make the movement imperceptible during the exposure.

##### **a. STABILIZATION**

Image stabilization may be achieved either optically (as Leighton at Cal. Tech. has done) or electronically in an Image Orthicon (as DeWitt, Hardie and Seyfert have done).

Although data on the frequencies and amplitudes of motion are sparse, it appears that the predominant motions occur at low frequencies, and that compensation up to 50 c.p.s. will probably be adequate.

Since the diameter of the field of view in which the seeing motions are coherent is small, a stabilizing technique may be applicable only to portions of the lunar image, although it appears adequate for the planets.

##### **b. INTENSIFICATION**

Owing to the limited quantum efficiency of photographic materials, exposure times cannot be made short enough to render the image motion imperceptible. Therefore we attempt to apply electronic light amplifiers to brighten the image sufficiently to attain the desired exposure time. There should be no instrumental loss of resolution if the technique is to be of value.

#### **II. IMAGE DILATION**

When the image is large and fuzzy neither short exposures nor intensification can be expected to help. Unfortunately this type of seeing occurs more frequently in large-aperture telescopes, while it is just these telescopes that are required for high-resolution photography.



Many factors are involved in producing this form of seeing, only some of which are subject to control. Site location and seasonal atmospheric conditions play an important part, and most major modern observatories have been located to optimize image quality. In regard to the control, or minimizing the influence of other factors, several techniques are worthy of consideration:

- a. Forced ventilation and temperature control of telescope and dome can have beneficial effects, as has been demonstrated by the French observers (Lyot, Rosch, Dollfus).
- b. When the seeing is good, work done in red light, where feasible, results in better seeing quality than that done in blue light. This has been recognized by visual observers, and is part of a discussion in a paper by Keller and Hardie on a theory of seeing.
- c. Recent experiments in apodization, by Strong and his associates and by French observers, indicate that the seeing-image profile can be substantially narrowed. The technique is designed to redistribute the light in a diffraction pattern in such a way as to eliminate the rings, and to thus improve contrast. Although the theoretical resolving power is made somewhat poorer, the seeing is improved owing to the increasingly low weight given to the outer portions of the objective which receive light having little correlation in wave-front distortion. Apodization for an objective occulted at the center (i.e., Cassegrainian or Newtonian) does not appear to be feasible; hence a refractor and an off-axis portion of a reflector are best suited for this kind of correction. Further critical experiments in this direction are desirable.
- d. A possible means of correction of the wave-front distortion caused by seeing was discussed some years ago by Dr. Horace Babcock. Although this has not been applied, and indeed may not be applicable in the form described, it should be re-examined critically with the aim of developing an applicable technique.
- e. Another means of correction may lie in an analytical method. Basically, the image contour for a star as broadened by seeing supplies information which may in principle be used to reconstruct an image from which seeing distortion has been removed. Such experiments may also lead to higher-resolution photography.

## F. LUMICON PERFORMANCE

Evidence of the high efficiency of this closed-circuit TV device is afforded by its speed in obtaining photographs of faint nebulae. This particular property results from the higher quantum efficiency of its photoelectric cathode, and the excellent integration properties of the target in the G. E. Orthicon, which permits long exposures to be made. Nevertheless, the closed-circuit TV system is still about 10 times poorer than the eye, and this seems to imply that the full efficiency of the photoelectric device is not exploited, since they ought to be about equivalent under the best circumstances. This is important since the finest detail seen by the eye on planetary and lunar surfaces undoubtedly stems from its high efficiency in detecting small differences in brightness.

Several factors are responsible for the loss of efficiency in the Orthicon tube.

- i. The cathode material is not the most efficient procurable; it is probably about 5 to 10% efficient in the present case.
- ii. The target mesh occults about 50% of the incoming electrons, bringing the efficiency down to 2 to 5%.
- iii. The noise in the sweeping beam limits the minimum detectable light level. This will only be negligible for strong signals (bright image).

In addition to the somewhat restricted efficiency, the closed-circuit TV unit used did not achieve the best possible definition. The reasons for this are not at once obvious, but several causes may be suggested.

a) In principle, the smallest details in an image are limited by the screen size in the target mesh. These are of the order of  $1/750$  inch; thus in an inch, 750 picture elements are available. If this element size is matched to the optical resolving power, then one is sure that the instrument will not limit the definition; only the seeing will be effective in causing poor definition. For the 82-inch telescope the resolving power is about  $1/20$  of a second of arc, or  $1/140$  mm at the Cassegrainian focus. Thus in an inch there are in principle about 3500 picture elements available. Hence an enlarging lens having a power of about 5 is called for. Although this severely restricts the area under examination it is necessary if the theoretical resolving power is to be achieved.



In spite of this, the photographs appeared to be limited in definition by the instrument. It is probable that the interlaced sweep contributes to this lack of definition, and for astronomical purposes there is no need for interlacing in any case.

b) Another difficulty experienced in the case of lunar work was the high intensity of the image. It would have been advantageous to incorporate a switching circuit in the photocathode circuit which would permit the device to accept an image of only 1/30 sec duration when desired.

c) The limited range in brightness is a serious handicap. This results from a range limitation within the target, from the necessity of adjusting the beam current for a narrow range of target charge, and from any possible limitations imposed by the amplifier circuits. One step in the direction of improvement would be to reduce the potential between photocathode and target, and thus reduce the multiplication factor at the targets (only certain specific voltages are permissible owing to the magnetic focusing).

d) A number of defects of a minor nature in the operation of the equipment became apparent from time to time. For this reason, and for reasons of modifying the design in the various manners indicated above, it would appear highly desirable to have on hand at all times an engineer who is intimately familiar with the device. In this manner the fullest exploitation of the instrument's potential may be made, and basic research and development could be made.

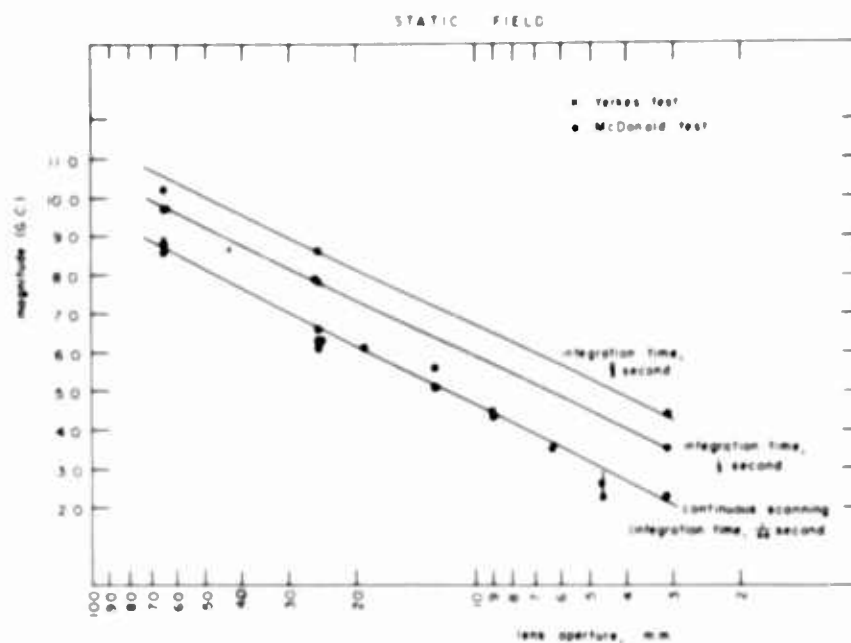


Figure 1. Showing limiting magnitude vs. aperture for Yerkes and McDonald tests.

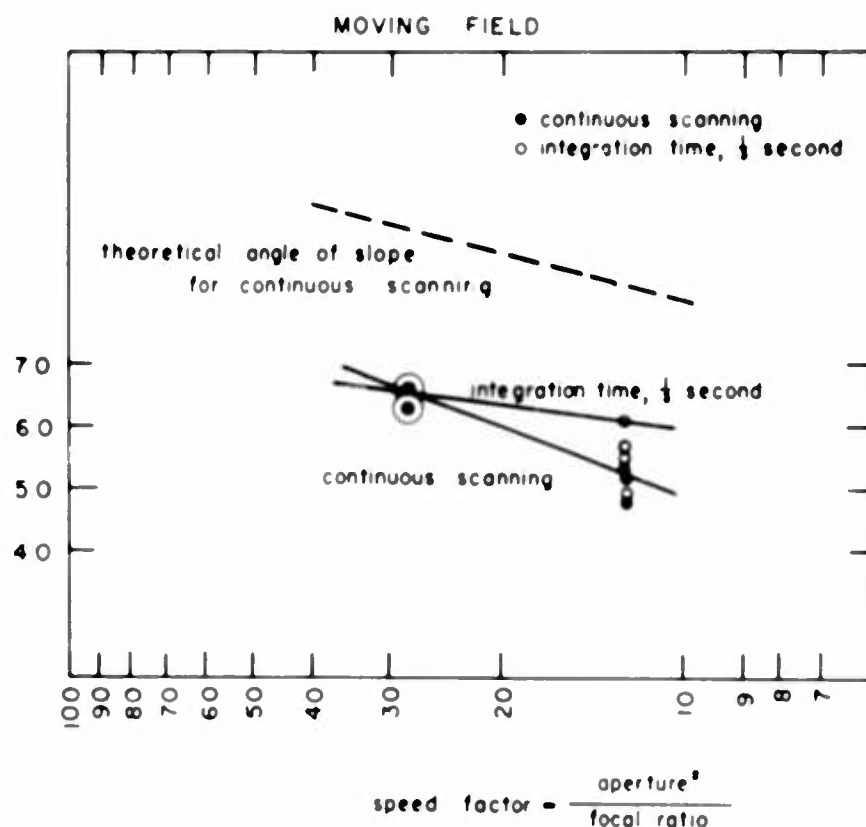
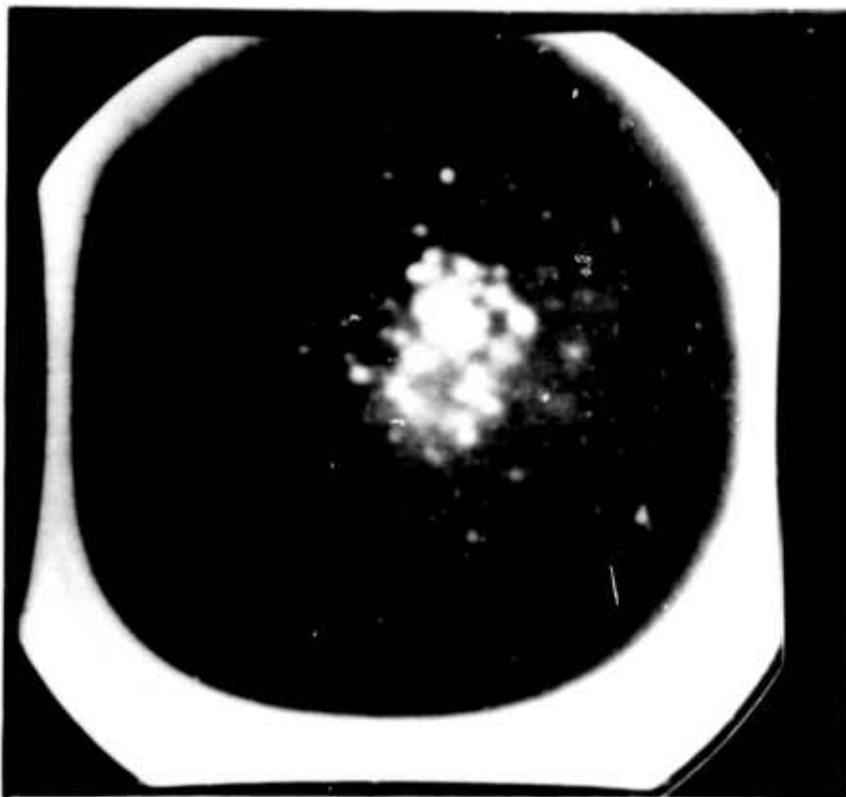


Figure 2. Showing limiting magnitude vs. the ratio of (aperture)<sup>2</sup>/focal length (being the intensity per unit length of the trail). McDonald tests.



**Figure 3.** NGC4147, 3 sec. integration, Cassegrainian focus,  
82-inch telescope, March 1959.

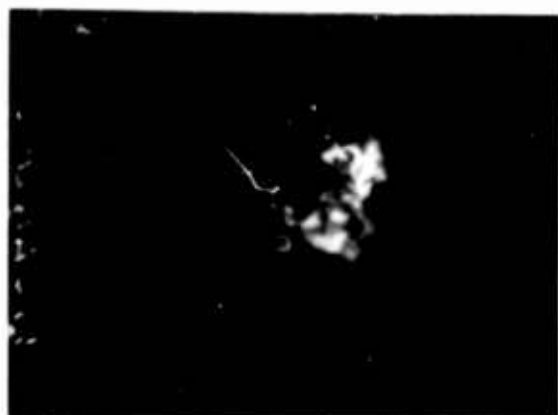


Figure 4. Orion nebula, 40-inch telescope, yellow filter,  
1/2 sec. integration. January 20, 1959.

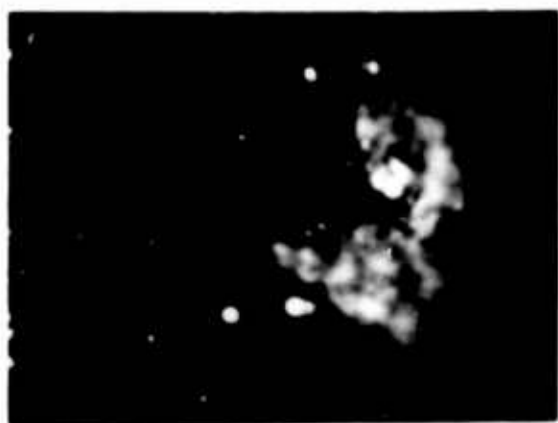


Figure 5. As Figure 4, but 2 sec. integration.

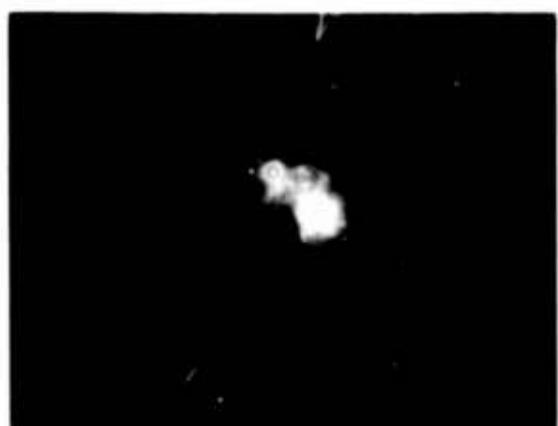
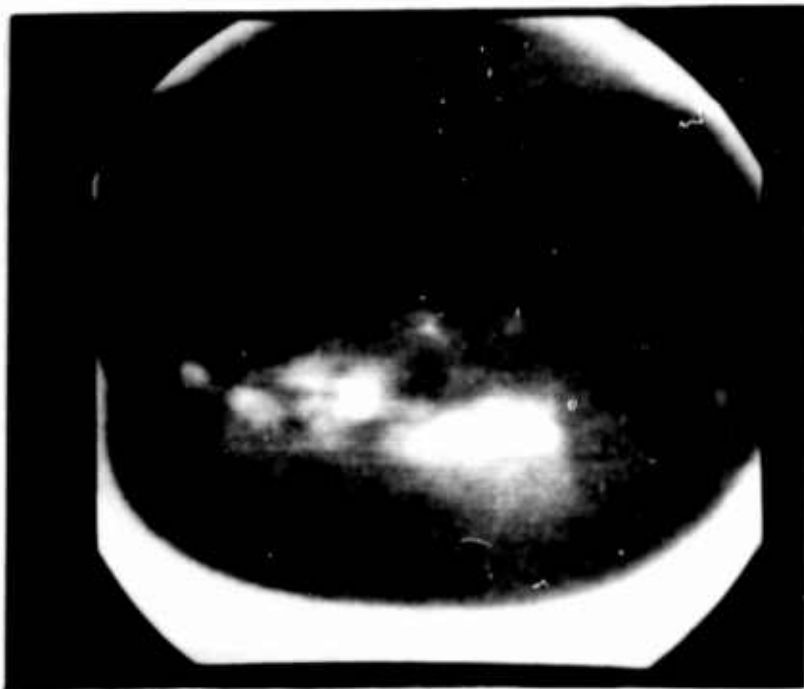
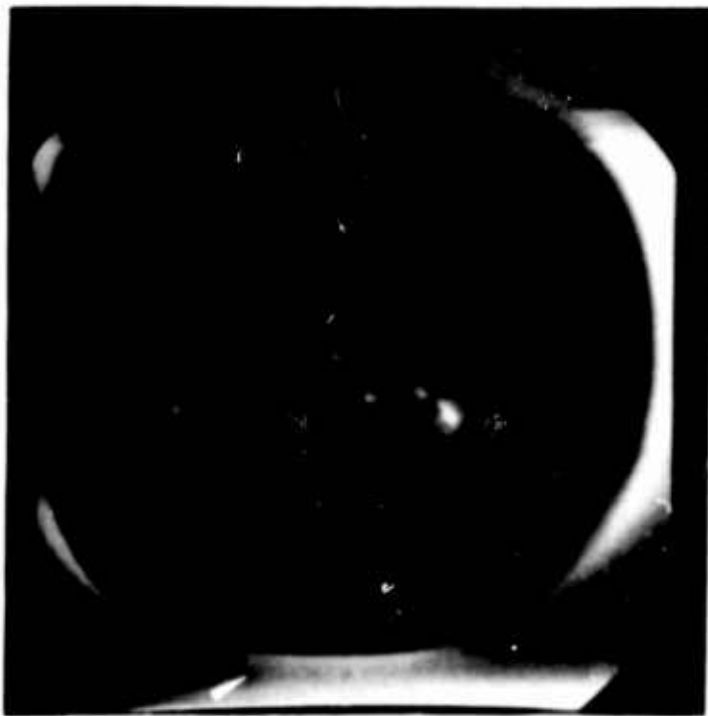


Figure 6. Orion nebula, 40-inch telescope, yellow filter,  
direct photograph - IG, 20 min. exposure,  
October 27, 1937.



**Figure 7.** M82, 82-inch telescope, 2 sec. integration.



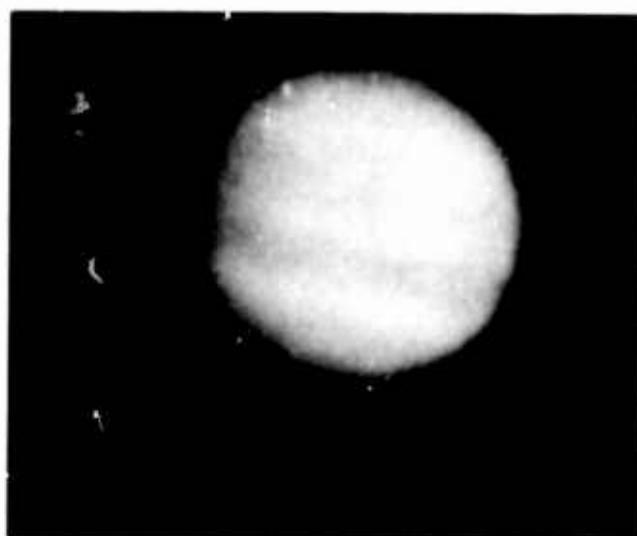
**Figure 8.** Same, with better seeing, but plate underdeveloped.



Figure 9. Nucleus of M87, NGC4486 and "jet", 82-inch,  
1.5 sec. integration.



**Figure 10.** Jupiter, 82-inch telescope, 1/30 sec. sweep,  
March 23, 1959, planet low in sky, seeing poor.



**Figure 11.** Jupiter, 82-inch telescope, direct photograph  
exposure 2 sec. same date as Fig. 10.  
Planet low in sky, seeing poor.



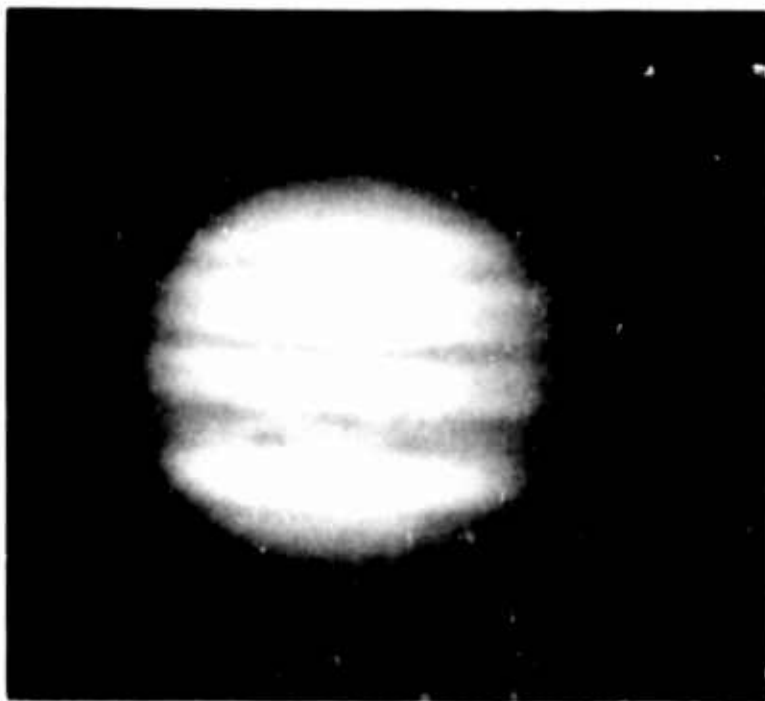


Figure 12. Jupiter, 40-inch  $f = 63$  feet, direct exposure, 2 sec., July 10, 1959.

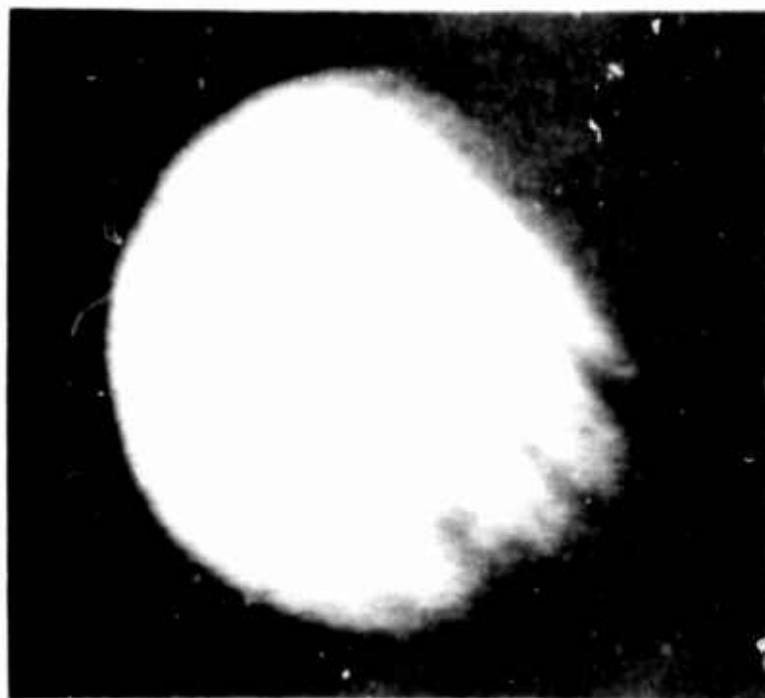
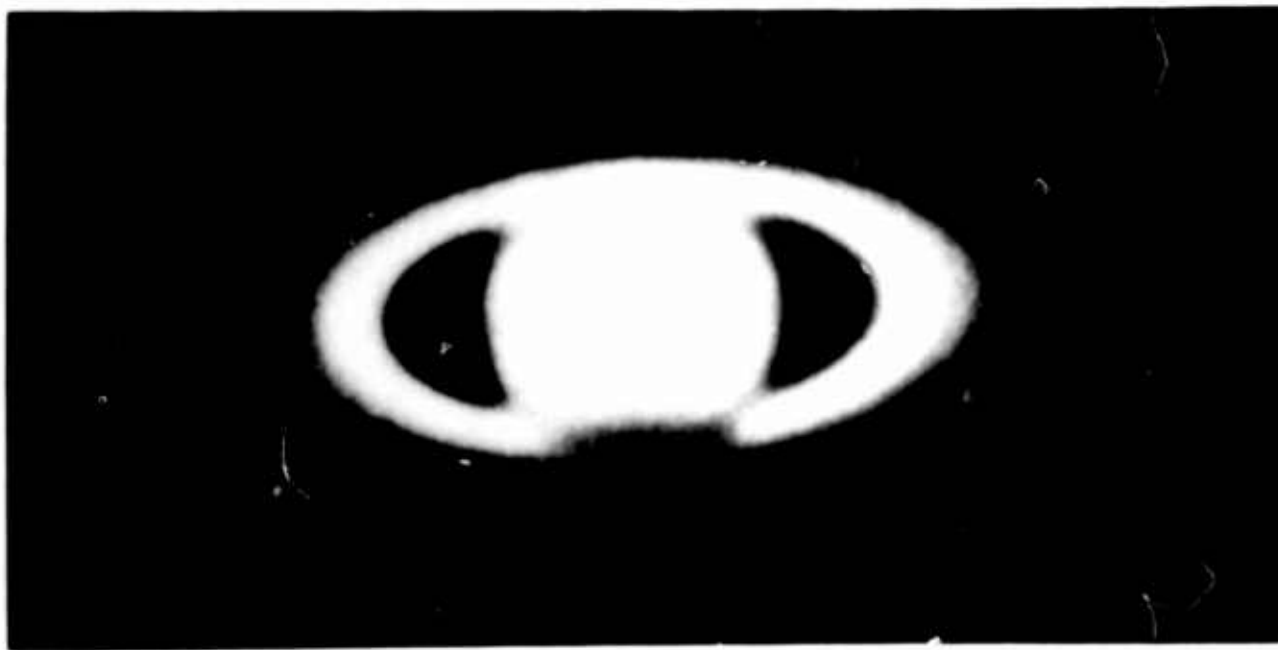


Figure 13. Jupiter, 40-inch,  $f = 300$  feet, Lumicon, sweep 1/30 sec., July 10, 1959.



**Figure 14.** Saturn; 40-inch  $f = 63$  feet, direct exposure, 2 sec,  
July 10, 1959.



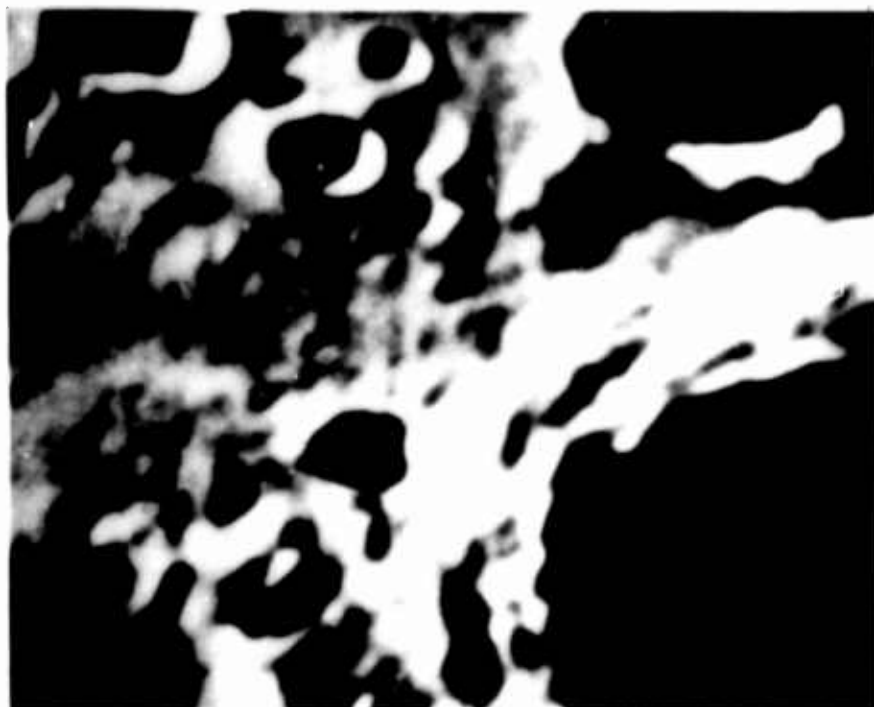
**Figure 15.** Saturn; 40-inch  $f = 300$  feet, Lumicon, sweep  
1/30 sec., July 10, 1959.



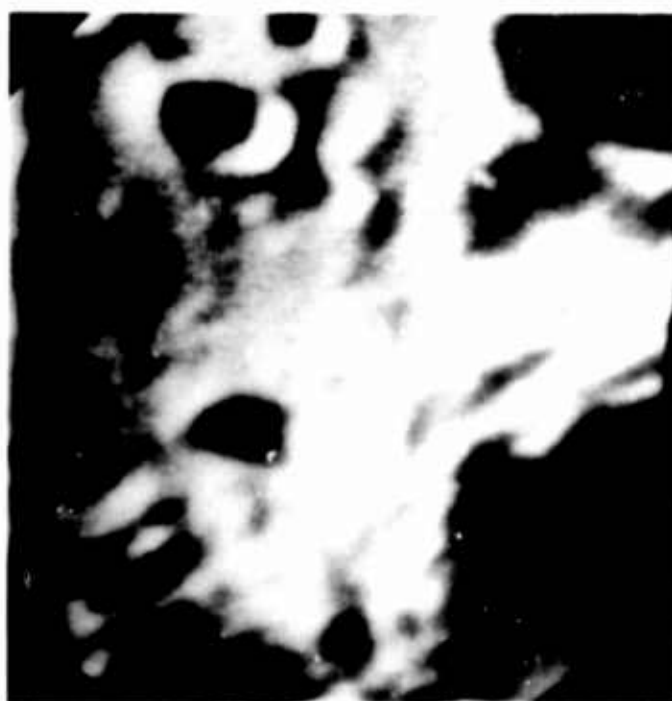
Figure 16. Crater Burg and Faults, 40-inch  $f = 63$  feet, direct exposure, 2 sec., July 10, 1959.



Figure 17. Crater Burg and Faults, 40-inch  $f = 300$  feet, direct exposure, 2 sec., July 10, 1959.



**Figure 18.** Lunar detail, 40-inch  $f = 63$  feet, direct exposure, 2 sec., July 10, 1959.



**Figure 19.** Lunar detail, 40-inch  $f = 300$  feet, Lumicon sweep  $1/30$  sec., July 10, 1959.